

the claw is stronger and stronger. This, too, accords with the habits of the crayfish, which will almost sooner die than let go its prey when seized. Thus between the two chief muscles of the crayfish there is a difference at least as considerable as between the striated and non-striated muscles of vertebrates.

### SUSPENDED ANIMATION

THE statements in the *Times* of Monday, which, under the head of "A Wonderful Discovery," are copied from the *Brisbane Courier*, seem greatly to have astonished the reading public. To what extent the statements are true or untrue it is impossible to say. The whole may be a cleverly-written fiction, and certain of the words and names used seem, according to some readers, to suggest that view; but be this so or not, I wish to indicate that some part, at all events, of what is stated might be true, and is certainly within the range of possibility.

At once let me state that the discovery, so called, which is described in the communication under notice, is not in principle new. On the subject of suspension of animation I have myself been making experimental inquiries for twenty-five years at least, and have communicated to the scientific world many essays, lectures, and demonstrations relating to it. I have twice read papers bearing on this inquiry to the Royal Society, once to the British Association for the Advancement of Science, two or three times in my lectures on Experimental and Practical Medicine, and published one in *NATURE*. In respect to the particular point of the preservation of animal bodies for food, I dwelt on this topic in the lectures delivered before the Society of Arts in April and May of last year, 1878, explaining very definitely that the course of research in the direction of preservation must ultimately lead to a process by which we should keep the structures of animals in a form of suspended molecular life.

Let me next point out what, by experiment, is known as to the possibility of suspending animal life.

If an animal perfectly free from disease be subjected to the action of some chemical agents or physical agencies which have the property of reducing to the extremest limit the motor forces of the body, the muscular irritability, and the nervous stimulus to muscular action, and if the suspension of the muscular irritability and of the nervous excitation be made at once and equally, the body even of a warm-blooded animal may be brought down to a condition so closely resembling death, that the most careful examination may fail to detect any signs of life. I have shown in a Croonian lecture that there are three degrees of muscular irritability to which I have given the names of active efficient, passive efficient, and negative. The first of these states is represented in the ordinary living muscle in which the heart is working at full tension, and all parts of the body are thoroughly supplied with blood, with perfection of consciousness in waking hours, and, in a word, full life. The second of these states is represented in suspended animation, in which the heart is working regularly, but at low tension, supplying the muscles and other parts with sufficient blood to sustain the molecular life, but no more. The third of these states is represented when there is no motion whatever of blood through the body, as in an animal entirely frozen.

The second stage, the stage of passive efficiency, is that in which animation is usually suspended. The condition is a close semblance to the third stage, but differs from it in that under favouring circumstances the whole of the phenomena of the active efficient stage may be perfectly resumed, the heart suddenly enlarging in volume, from its filling with blood, and reanimating the whole organism by the force of its renewed stroke, in full tension.

So far as we have yet proceeded, the whole phenomena of restoration from death are accomplished during this

stage. To those who are not accustomed to see them, they are no doubt very wonderful, looking like veritable restorations from death. They surprise even medical men the first time they are witnessed by them.

At the meeting of the British Medical Association at Leeds, a member of the Association was showing to a large audience the action of nitrous oxide gas, using a rabbit as the subject of his demonstration. The animal was removed from the narcotising chamber a little too late, for it had ceased to breathe, and it was placed on the table, to all appearances dead. At this stage I went to the table, and by use of a small pair of double-acting bellows restored respiration. In about four minutes there was revival of active irritability in the abdominal muscles, and two minutes later the animal leaped again into life, as if it had merely been asleep. There was nothing remarkable in the fact, but it excited, even in so cultivated an audience as was then present, the liveliest surprise.

The time during which an animal body may be capable of re-animation from the state of passive efficiency depends altogether on one circumstance, viz., whether the blood, the muscular fluid, and the nervous fluid remain, in a condition which I have defined in another essay as the aqueous condition, or whether these fluids have become pectous. If the fluids remain in the aqueous state, the period during which life may be restored is left undefined. It may be a very long period, including weeks, and possibly months, granting that decomposition of the tissues is not established, and even after a limited process of decomposition, there may be renewal of life in cold-blooded animals. But if pectous change begins in any one of the structures I have named, it extends like a crystallisation quickly through all the structures, and thereupon recovery is impossible, for the change in one of the parts is sufficient to prevent the restoration of all. Thus the heart may be beating, but the blood being pectous it beats in vain; or the heart may beat and the blood may flow, but the voluntary muscles being pectous, the beating is in vain; or the heart may beat, the blood may flow, and the muscles may remain in the aqueous condition, but the nerves being pectous the circulating action is in vain; or sometimes the heart may come to rest and the other parts may remain susceptible, but the motion of the heart and blood not being present to quicken them into activity, their life is in vain.

The problem physiologically before us is as follows:—Can the second or passive efficient stage of life be by any artificial methods secured, so that all the vital parts may be held in suspended animation, working at the lowest possible expenditure of vital power?

Experimental research and experience alike show the certain possibility of temporarily producing this state. Both show that there are agents and agencies by which life may be reduced to the low ebb necessary for suspension of active life, and at the same time the aqueous conditions of the colloidal fluids may be maintained. Cold is the first and most efficient of these agencies. The blood and the colloidal animal fluids derived from it are all held in the aqueous condition of colloidal matter by exposure to cold at freezing-point. At this same point all vital acts, excepting, perhaps, the motion of the heart, may be temporarily arrested in an animal, and then some animals may continue apparently dead for long intervals of time, and may yet return to life under conditions favourable to recovery.

In one of my lectures on death from cold, which I delivered in the winter session of 1867, some fish, which, during a hard frost, had been frozen in a tank at Newcastle-on-Tyne, were sent up to me by rail. They were produced in the completely frozen state at the lecture, and by careful thawing many of them were restored to perfect life. At my Croonian lecture on muscular irritability after systemic death, a similar fact was illustrated from frogs.

There seems in cold-blooded animals so circumstanced to be no recognisable limit of time after which they may not recover, but there is much skill required in promoting the recovery. If in thawing them the utmost care be not taken to thaw gradually, and at a temperature always below the natural living temperature of the animal, the fluids of the animal will pass from the frozen state through the aqueous into the pectous so rapidly that death from pectous change will be pronounced without perceiving any intermediate or life-stage at all. In warm-blooded animals it is extremely difficult to restore animation after suspension of life by cold, owing to the fact that in their more complex and differently-shielded organs, it is next to impossible to thaw equally and simultaneously all the colloidal fluids. In very young animals it can be done. Young kittens, a day or two old, that have been drowned in ice cold water, will recover after two hours' immersion almost to a certainty, if brought into a dry air at a temperature of 98° F. The gentlest motion of the body will be sufficient to restart the respiration and therewith the life.

The nearest approach we see naturally to this state is in hibernating animals. In them the effects of cold in the season for hibernation and the recovery from the torpor are seen even in matured and old animals. In hibernation, however, there is not produced the complete stage of passive efficiency. There is in them a slow respiration and a low stage of active efficiency of circulation. The hibernating animal sleeps only; and while sleeping it consumes or wastes, and, if the cold be prolonged, it may die from wasting. From the sleep of hibernation also the animal can be roused by the common methods used for waking a sleeper, so that animation is not positively suspended.

Returning to the extreme effects of cold on animal bodies, it is hard to say whether an animal like a fish, frozen equally through all its structures, is actually dead, in the strict sense of the word, seeing that if it be uniformly and equally thawed it may recover from a perfect glacial state. In like manner it may be doubted whether a healthy warm-blooded animal, suddenly and equally frozen through all its parts, is dead, although it is not recoverable, because, in the very act of trying to restore it, some inequality in the direction is almost sure to determine a fatal issue owing to the transition of some vital centre into the pectous state of colloidal matter. I do not, consequently, see that cold can be of itself and alone utilized for maintaining suspended animation in the larger warm-blooded animals of full growth. At the same time cold will, for a long time, maintain, ready for motion, active organs locally subjected to it. Even after death this effect of it may be locally demonstrated, and has sometimes been so demonstrated to the wonder of the world. On January 17, in the year 1803, Aldini, the nephew of Galvani, created the greatest astonishment in London by a series of experiments which he conducted on a malefactor, twenty-six years old, named John Forster, who was executed at Newgate, and whose body, an hour after execution, was delivered over to Mr. Keate, Master of the College of Surgeons, for research. The body had been exposed for an hour to an atmosphere two degrees below freezing-point, and from that cause, though Aldini does not seem to have recognized the fact, the voluntary muscles retained their irritability to such a degree that when Aldini began to pass voltaic currents through the body some of the bystanders seem to have concluded that the unfortunate malefactor had come again to life. It is significant also that Aldini, in his report, says that his object was not to produce re-animation, but to obtain a practical knowledge how far galvanism might be employed as an auxiliary to revive persons who were accidentally suffocated, as though he himself were in some doubt.

In repeating Aldini's experiments on lower animals that had passed into death under chloroform, with the view of determining what is the best treatment for those human beings who sink under chloroform and other anæsthetics, I failed altogether to obtain the same results when the temperature of the day was high. Noticing this, I experimented at or below freezing-point, and then found that both by the electrical discharge and by injection of water heated to 130° F. into the muscles through the arteries, active muscular movements could be produced in warm-blooded animals many hours after death. Thus, for lecture experiment I have removed one muscle from the body of an animal that had slept to death from chloroform, and, putting the muscle in a glass tube surrounded with ice and salt, I have kept it for several days in a condition for its making a final muscular contraction, and, by gently thawing it, have made it, in the act of final contraction, do some mechanical work, such as moving a long needle balanced on the face of a dial, or discharging a pistol.

In muscles so removed from the body and preserved ready for motion, there is, however, only one final act. For, as the blood and nervous supply are both cut off from it, there is nothing left in it but the reserve something that was fixed by the cold; but I do not see any reason why this should not be maintained in reservation for weeks or months, as easily as for days, in a fixed cold atmosphere.

Besides cold there are other agencies which hold the colloidal fluids in the aqueous state, and which, while they suspend the motor function, suspend without necessarily destroying life. Several agents of this class have been discovered.

*Mandragora*.—The first known of these suspending agents was mandragora. This was known as far back as Dioscorides. Dioscorides states that this vegetable substance may be administered in such a manner that the signs of active life may disappear, and sensibility be so far destroyed that the physician or surgeon may operate on the temporarily insensible without producing pain. The suspension of life from mandragora may extend over some hours, and the use of the agent probably was continued until the twelfth or thirteenth century. From the action of it doubtless comes the Shakespearian legend of Juliet. In modern times I have made the wine of mandragora, and found that it has the power originally attributed to it of suspending without destroying active life. The wine from it was the morion of the ancients, the fluid probably that was used by the Jewish women in the times of the Sanhedrim to destroy the sufferings of those who were under torture, and sometimes, perchance, to deceive the executioner and prevent the deadliness of his task.

The plant from which morion was originally made, the *Atropa belladonna* (deadly nightshade), has, in this country, similar properties to its ally the *Atropa mandragora*. In 1851 I attended at Mortlake two children who were poisoned for a time from eating the berries and chewing the leaves of the nightshade which they had gathered near to Richmond. The children were brought home insensible, and they lay in a condition of suspended life for seven hours, the greatest care being required to detect either the respiration or the movements of the heart. They nevertheless recovered.

*Nitrite of Amyl*.—In my original researches on the nitrite of amyl, one of the observations which most surprised me was the power of this agent to suspend animation. In the report I made to the British Association in 1864 on this subject, I showed that the life of the frog might be suspended for the period of nine days, and yet recovery to full and vigorous life might follow; that the same power of suspension, in a lesser degree, could be produced in warm-blooded animals, and that the heart of a warm-blooded animal would contract for the period of eighteen



hours after apparent death. The action of the nitrite of amyl in causing suspended animation seemed to be like cold. It prevented the pectous change of colloidal matter, and so prevented rigor mortis, coagulation of blood, and solidification of nervous centres and cords. So long as this change was suspended return of vital function was possible. When the pectous change occurred, all was over, and resolution into new forms of matter by putrefaction was the result.

From the analogy of some of these symptoms from nitrite of amyl with the symptoms of the disease called catalepsy, I have ventured to suggest that, under some abnormal conditions, the human body itself, in its own chemistry, may produce an agent which causes the suspended life observed during the cataleptic condition.

*Woorali* in a similar manner suspends vital function; but as the influence of this agent has been more frequently under observation from other physiologists, I leave it with this mention of it.

*Chloral Hydrate* has many of the properties of the other substances named above in its power of suspending life. At the meeting of the British Association at Exeter, at which I made the earliest report in this country of Liebreich's remarkable discoveries, some pigeons, which had been put to sleep by the needle-injection of a large dose of chloral, fell into such complete resemblance of death, that they passed among an audience containing many physiologists and other men of science for dead. For my own part I could detect no sign of life in them, and they were laid in one of the out-offices of the museum of the infirmary as dead. In this condition they were left late at night, but in the following morning they were found alive and as well as if nothing hurtful had happened to them.

*Cyanogens.*—Cyanogen gas and hydrocyanic acid, deadly poisons as they are, have the power in a singular degree of suspending animation. Combined with a sufficient degree of cold to prevent their evaporation from the body, their suspending power is of the most definite kind. In the laboratory of a large drug establishment a cat, by request of its owner, was killed, as it was assumed, instantaneously and painlessly by a large dose of Scheele's acid. The animal appeared to die without a pang, and presenting every appearance of death was laid in a sink to be removed on the next morning. At night the animal was lying still in form of death in the tank beneath a tap. In the morning it was found alive and well, but with the fur wet from the dropping of water from the tap. This fact was communicated to me by the eminent chemist under whose direct observation it occurred, in corroboration of an observation of mine similar in character.

*Alcohol* is another substance which holds the vital functions in suspense for long periods of time, the muscles retaining their excitability. In animals killed by alcohol in combination with cold, two influences which act powerfully together in the same direction, I found the muscular excitability could be retained at freezing-point for several hours even in birds. A remarkable similar experience, which I have elsewhere recorded, was obtained in the case of an intoxicated man who, while on the ice at the Welsh Harp lake, fell into the water through a breakage in the ice, and who for more than fifteen minutes was completely immersed. This man was extricated to all appearances dead, but under artificial respiration, carried out by my friend Dr. Belgrave, of Hendon, he was restored to consciousness and lived for several hours.

*Oxygen.*—It is not a little singular that pure oxygen gas possesses the power of suspending life, at all events in muscular fibre, when it is aided by condensation produced by cold; but I am on new ground here, with which I am not so conversant at present as I hope to be.

I have now shown as briefly as was possible that much

is known in the world of science in respect to suspension of animal life by artificial means. It will be seen that cold as well as various chemical agents has this power; and it is worthy of note that cold, together with the agents named, is antiseptic, as though whatever suspended living action, suspended also by some necessity or correlative influence the process of putrefactive change. Hence the influence I drew in my lecture at the Society of Arts, that it was within the range of experiment to preserve the structures of dead animals in a form of suspended molecular life.

If the experiments reported from Brisbane be reliable it is clear, I think, that what has been done has been effected by the combination of one of the chemical agents above named, or of a similar agent, in combination with cold, the efficiency of which combination we have seen in many of the experimental facts referred to above. The only question that exists as of moment is, not whether a new principle has been developed, but whether, in matter of detail, a new product has been discovered which, better than any of the agents we already possess, destroys and suspends animation. In organic chemistry, there are, I doubt not, hundreds of substances which, like mandragora and nitrite of amyl, would suspend the vital process, and it may be that a new experimenter has met with such an agent. It is not incredible indeed that the Indian Fakirs possess a vegetable extract or essence which possesses the same power, and by means of which they perform their as yet unexplained feat of prolonged living burial; but I confess, on reading the Australian narrative, there is nothing suggested by it to my mind that might not be produced by agents already known. Making allowance for what is clearly a very enthusiastic description, there is nothing in an experiment related as made on a dog that might not have been produced by the subcutaneous injection of hydrate of chloral; neither is there anything in other experiments that might not follow from the injection of chloral or woorali in a cold atmosphere. At the same time it is not also unreasonable to infer that a new product has been found which surpasses any we possess, and suspends animation for a longer period. My faith is most shaken first by the statement that the agent referred to is a secret, for men of true science know no such word; secondly, that the experimenter has himself to go to America to procure more supplies of his agents; and thirdly, that he requires two agents, one of which is antidotal to the other. I can understand the production of a definite effect from a single; and others as well as myself have made out a great many facts respecting the antagonism of one agent by another. But in our researches on antagonistic physiological substances we require the agencies of absorption and circulation of the antidote, and how in a body bereft of motion and practically dead such absorption can take place I am unable to divine.

But even should the description given by the Australian journalist prove overdrawn or imaginative, I am not sorry it has appeared, since it has afforded a reason for relating in a plain and faithful manner to what actual extent human knowledge has been advanced by experiment on the subject under consideration. This duty, though it be but preliminary, is important as an introduction to those great events which in the future are sure to come from the positive results that have already been secured, and for which the world should be prepared, without anxiety or amazement.

BENJAMIN WARD RICHARDSON

## NOTES

THE death is announced of William Froude, F.R.S., a name familiar to our readers in connection with experiments on wave-resistances and the form of ships. Mr. Froude, who had long